Differential Draining of Parallel-Fed Propellant Tanks in Morpheus and Apollo Flight

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Parallel-fed propellant tanks are an advantageous configuration for many spacecraft. Parallel-fed tanks allow the center of gravity (cg) to be maintained over the engine(s), as opposed to serial-fed propellant tanks which result in a cg shift as propellants are drained from tank one tank first opposite another. Parallel-fed tanks also allow for tank isolation if that is needed. Parallel tanks and feed systems have been used in several past vehicles including the Apollo Lunar Module. The design of the feedsystem connecting the parallel tank is critical to maintain balance in the propellant tanks. The design must account for and minimize the effect of manufacturing variations that could cause delta-p or mass flowrate differences, which would lead to propellant imbalance. Other sources of differential draining will be discussed. Fortunately, physics provides some self-correcting behaviors that tend to equalize any initial imbalance. The question concerning whether or not active control of propellant in each tank is required or can be avoided or not is also important to answer. In order to provide data on parallel-fed tanks and differential draining in flight for cryogenic propellants (as well as any other fluid), a vertical test bed (flying lander) for terrestrial use was employed. The Morpheus vertical test bed is a parallel-fed propellant tank system that uses passive design to keep the propellant tanks balanced. The system is operated in blow down. The Morpheus vehicle was instrumented with a capacitance level sensor in each propellant tank in order to measure the draining of propellants in over 34 tethered and 12 free flights. Morpheus did experience an approximately 20 lbm imbalance in one pair of tanks. The cause of this imbalance will be discussed. This paper discusses the analysis, design, flight simulation vehicle dynamic modeling, and flight test of the Morpheus parallel-fed propellant. The Apollo LEM data is also examined in this summary report of the flight data.